DESIGN OF BARRICADES TO PREVENT PROMPT PROPAGATION

Michelle Crull, PhD, PE, US Army Engineering & Support Center, Huntsville, Attn: CEHNC-ED-SY-T (Crull), PO Box 1600, Huntsville, AL 35807-4301, (256) 895-1653, fax: (256) 895-1737, Michelle.M.Crull@hnd01.usace.army.mil

Abstract

Current requirements for determining the height of a barricade between two ammunition and explosives (AE) stacks are detailed in paragraph C5.3.2.3.2 of DoD 6055.9-STD, "DoD Ammunition and Explosives Safety Standards". Two factors of these requirements (i.e. establishing the reference point at the far edge of the stack and drawing a line 2 degrees above the line of sight from the reference point to the other stack) are causing construction and operational challenges due to the required height of the barricade for large stacks of AE.

This paper discusses some of the history of these requirements and proposed changes to these requirements. The fragmentation from stacks of munitions and the interaction zones resulting from detonation of stacks of munitions are discussed. Fragment trajectories and the impact of various barricade heights in mitigating fragments that can cause prompt propagation are presented. This paper details a proposal for changing the requirements for determining the height of a barricade between two AE stacks.

An example of an open storage area using both the current requirements for the barricades and the proposed requirements is shown. As the example will show, the proposed changes will result in significant savings without sacrificing safety.

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1.0 Introduction

Usually, when ammunition and explosives (AE) are stored in the open barricades are placed between the stacks to prevent prompt propagation between the stacks of AE in order to reduce the Quantity-Distance (QD) requirements. Use of properly designed barricades protect against prompt propagation due to low-angle, high velocity fragments. Barricades provide no protection against high-angle fragments or lobbed AE.

Current requirements for determining the height of a barricade between two AE stacks are detailed in paragraph C5.3.2.3.2 of DoD 6055.9-STD, "DoD Ammunition and Explosives Safety

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14. ABSTRACT
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Standards" [1]. Two factors of these requirements (i.e. establishing the reference point at the far edge of the stack and drawing a line 2 degrees above the line of sight from the reference point to the other stack) are causing construction and operational challenges due to the required height of the barricade for large stacks of AE.

A brief history of the height requirements for barricades to prevent prompt propagation between two AE stacks is discussed. Analyses of the reference point location and other factors contributing to the effectiveness of the barricade in preventing prompt propagation due to fragments are presented. Based on these analyses, conclusions are drawn and recommended changes to the barricade design requirements are proposed.

2.0 History of Barricade Design Requirements

Prior to 1974, barricades between two AE stacks were required to have "a crest at least 3 feet wide, with the earth at the natural slope on each side and with such elevation that any straight line drawn from the top of the sidewall of a magazine or operating building or the top of a stack containing explosives to any part of a magazine, operating building, or stack to be protected will pass through the mound" (berm) [2]. A change to the barricade height requirements was proposed by the Explosives Safety Branch of the Directorate of Aerospace Safety (AFIAS-G2), Headquarters U.S. Air Force (USAF). "The new "2-degree" theory proposed by AFIAS-G2 stated that a straight line drawn from the far edge of the top of a bomb at a 2-degree angle above the horizontal must at least pass below the 3-foot wide crest of the standard earth barricade." [3] To test the modular open storage concept and the "2-degree theory" the Air Force performed full scale explosive testing (Big Papa Tests) in 1967 at Hill Air Force Test Range in Utah [3].

2.1 Big Papa Tests

In July 1966 the Air Force was notified of problems encountered in stockpiling required munitions (bombs) at Southeast Asia air bases in compliance with existing explosives quantity-distance criteria. The problem was caused by the shortage of land upon which the bombs could be stored. A special study group searched for data and evidence which would identify those parameters pertinent to the propagation of sympathetic simultaneous (prompt) detonations of adjacent barricaded bomb stacks.

2.1.1 Study Group Findings and Recommendations

The study group discovered that very little planned experimentation had been accomplished in this area. The study also revealed that high-speed fragments impinging on adjacent stacks of bombs would be the most likely cause of sympathetic detonations and that barricades would be necessary to stop these fragments and prevent prompt propagation. This study group reached the following conclusions (paraphrased):

a. Properly constructed barricades in conjunction with specified QD relationships will
   (1) Prevent sympathetic detonation between quantities of mass-detonating explosives.
   (2) Prevent blast and fragment-induced propagation between quantities of explosives.

b. The current QD criteria could be revised to increase barricaded storage capacity of munition areas in combat zones.

c. Distances between quantities of explosives could be reduced through proper use of barricades.

d. Based on the study of the available accidental and planned explosive data, the munitions storage criteria established as a result of that effort should be considered for combat zone applications.

e. Application of these criteria would increase the storage capacity of combat zone munitions storage areas by a factor of approximately 2½.

f. Testing was required to substantiate this combat zone criteria.

g. Testing was also required to determine optimum barricade geometry for universal QD application for net weights of mass-detonating explosives in the 125,000 to 500,000 lb range.

Some of the primary recommendations of the study group were (paraphrased):

1. A modular concept of munitions storage should be utilized. A module was defined as a barricaded area containing a maximum of five cells separated from one another by an intermediate barricade (similar to the current modular storage cells requirements).

2. The net weight of explosives within each cell would not exceed 100,000 lbs (Note: Current standards permit 250,000 lbs per cell [1]). The distance between the nearest edge of the stacks of bombs in adjacent cells would be a minimum of 50 ft. These distance and weight requirements were based on a K factor of 1.1 in the QD formula $D = K\ W^{1/3}$ where D is the distance in feet between stacks of bombs and W is the net weight in pounds of explosives in each stack.

3. The distance between the nearest edge of stacks of bombs in adjacent modules would not be less than 200 feet. This value was based on a K factor of 2.5 applied to the total net weight of explosive content of the module.

4. A test program be conducted to develop minimum separation between single stacks of bombs in the 125,000 to 500,000 lb range as it was foreseen that the storage of 100,000 lbs per cell would only temporarily alleviate the problem.

2.1.2 Test Objectives

A four phase test program was designed and executed. The primary objectives of the test program were:

a. Determine minimum distance between single stacks of barricaded mass-detonating explosives to prevent simultaneous (prompt) detonation of adjacent stacks and to minimize non-simultaneous propagation.

b. Determine the validity of the criteria being used in the 100,000 lbs cell (5 cells per module) approved for combat zone use by the Vice Chief of Staff, USAF on 27 September 1966.

c. Determine if the detonation of a single general purpose bomb, with current explosives fill, within a stack would hurl other bombs into the air above the barricade and subsequently detonate the bombs suspended in the air, resulting in the detonation of adjacent bomb stacks by fragment impingement.

A secondary test objective was to obtain a substantial amount of airblast and ground shock data for use in future QD studies.

Phases I and II of the Big Papa Tests were designed to demonstrate the feasibility of reducing the barricaded aboveground storage QD criteria of K6 to the maximum practical extent for barricaded bomb storage in single stacks in the range of 125,000 to 500,000 pounds of high explosives. Phases I and II were also designed to prove the validity of the concept of the five cell module with the distance between explosives in adjacent cells based on K1.1. Phase III was designed to determine optimum barricade geometry and materials for use in munitions storage by comparing the fragment stopping effectiveness of six different barricades (4 vertical faced metal barricades, a soil-cement barricade, and a standard earth barricade). Phase IV was an attempt to determine what would happen when only one bomb in an 80 bomb donor stack was detonated. Phases I and II provide the information pertinent to this paper so only these phases will be discussed from this point.

Fragmentation surveys were conducted on Phases I, II and III. In Phases I and II, fragments were collected on two survey lines extending 5000 feet from the center of the donor at right angles to each other, one normal to the longitudinal axis of the bombs and one parallel to the longitudinal axis of the bombs. Fragments were collected at the barricaded intraline distance (K9 = 575 ft), barricaded public highway/railway distance (K30 = 1890 ft), barricaded inhabited building distance (K50 = 3150 ft), and unbarricaded inhabited building distance (K68 = 4310 ft) for 250,000 lbs and at 5000 ft (Note: The numbers provided are directly from the test report [3]). Figures 1 and 2 show the fragmentation survey plans for Phases I and II, respectively.

For Phases I and II, two sizes of bomb stacks were used. The 250,000 lb net explosive weight (NEW) stacks contained 191 M66A2 bombs and 62 M117 bombs. The tops of these stacks were approximately 8 ft 10 in above the top of the concrete pad (~ 2 ft 2 in below the top of the earth barricade). The 75,000 lb NEW stacks contained 55 M66A2 bombs and 26 M117 bombs. The tops of these stacks were approximately 6 ft 4½ in above the top of the concrete pad (~ 4 ft 7½ in below the top of the earth barricade). Typical stack layouts are shown in Figures 3 and 4.

The test configuration for Phase I is shown in Figure 5. There was a 250,000 lb donor stack, a 250,000 lb acceptor stack (A1) and four 75,000 lb acceptor stacks (A2, A3, A4, and A5). The 250,000 lb acceptor stack was separated from the donor by a distance of K1.1. The 75,000 lb acceptor stacks were separated from the donor by the following distances: A2 at K0.9, A3 at K1.1, and A4 at K2.5. Acceptor A5 was separated from acceptor A1 by a distance of K2.5. All stacks were placed on 9 in thick reinforced concrete pads. The tops of the barricades were 11 ft above the concrete pads.

The test configuration for Phase II is shown in Figure 6. The donor stack was 250,000 lbs and the three acceptor stacks (A1, A2, and A3) were 75,000 lbs each. Acceptors A1 and A3 were separated from the donor by a distance of K1.1 and A2 was separated from the donor by a distance of K0.8. The donor stack and acceptors A2 and A3 were placed on 9 in thick reinforced concrete pads while acceptor A1 was placed on timber dunnage directly on the ground surface.

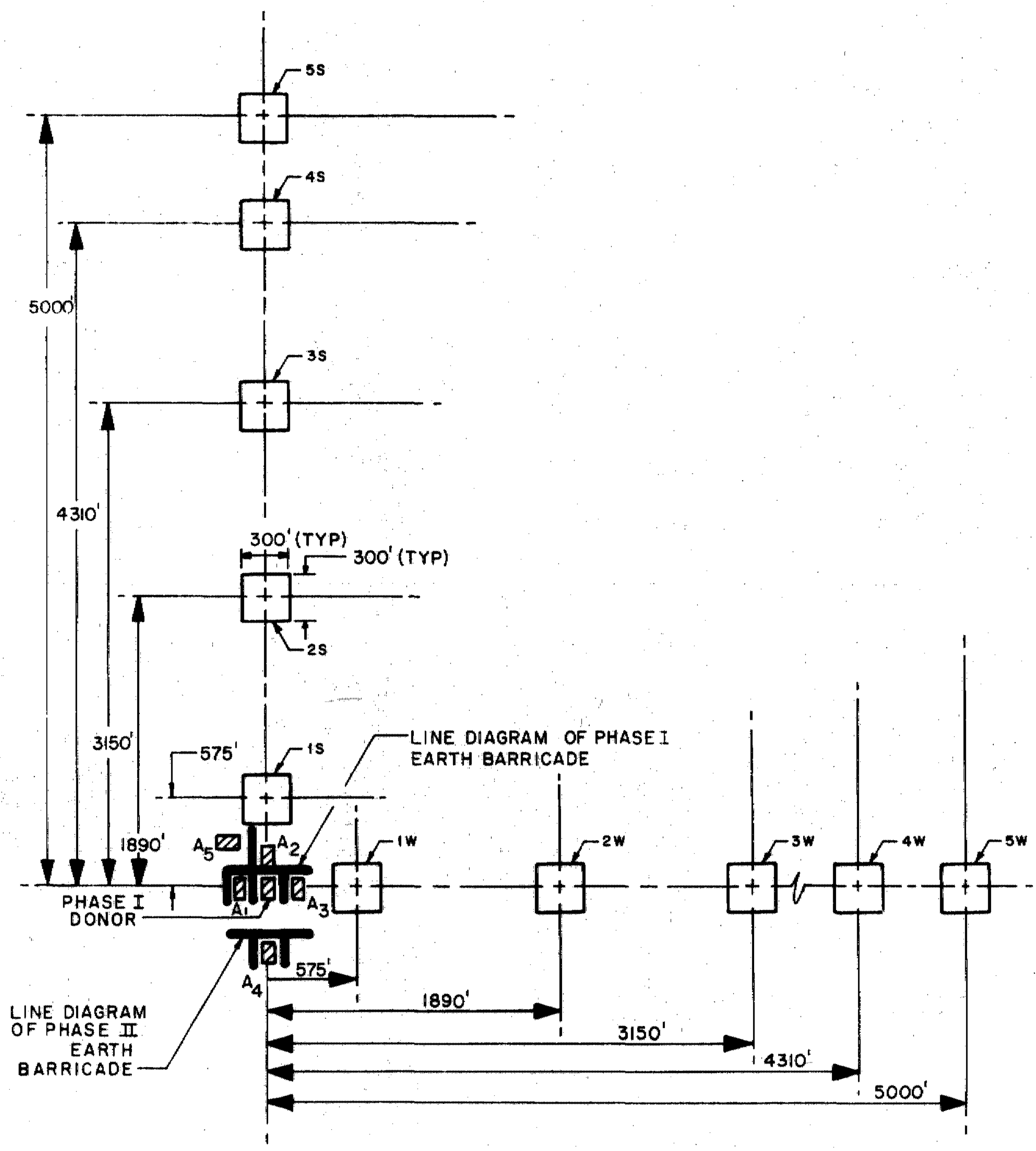


Figure 1 – Fragmentation Survey Plan for Phase I [3]

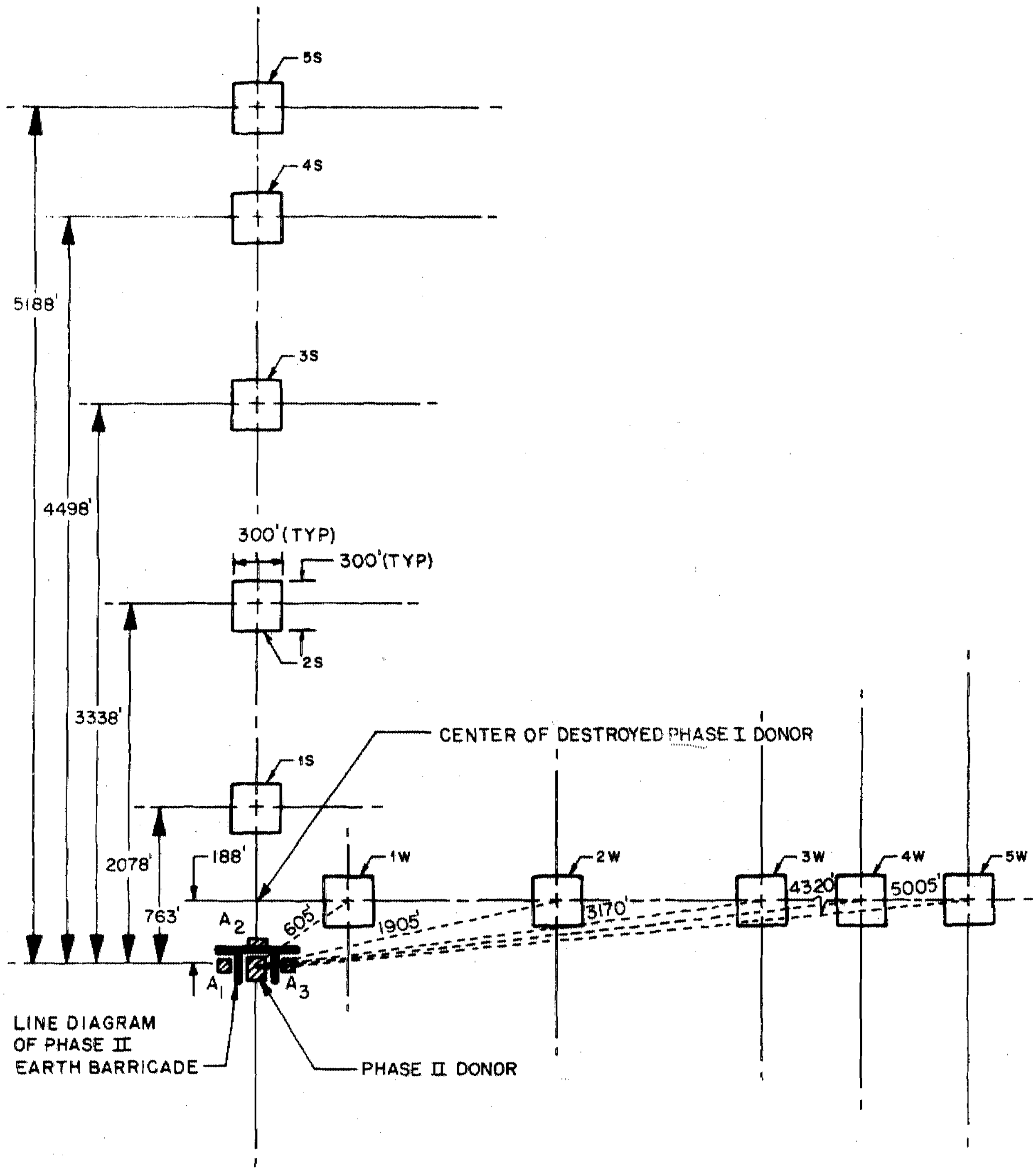


Figure 2 – Fragmentation Survey Plan for Phase II [3]

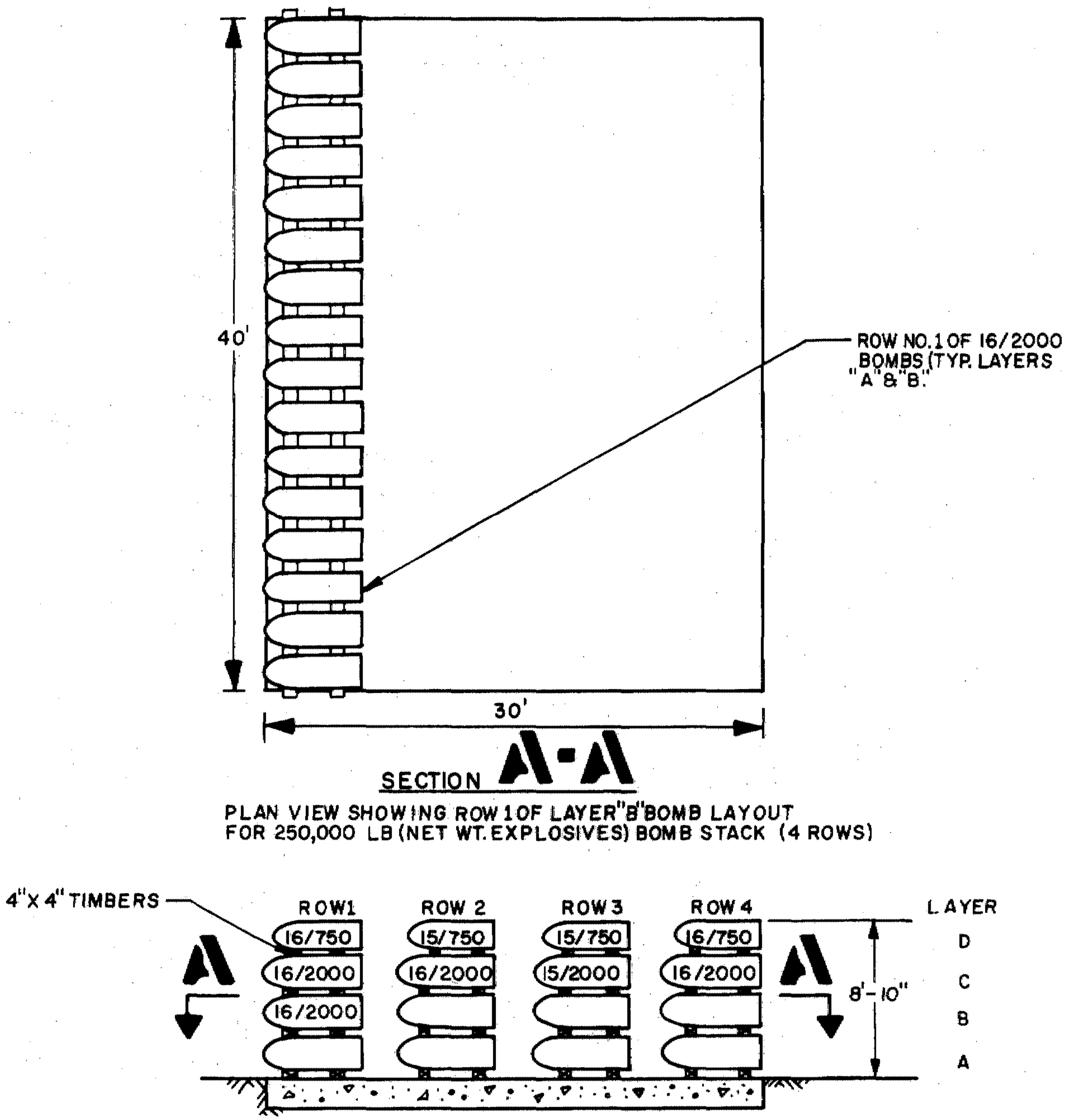


Figure 3 – Typical Bomb Arrangement for 250,000 lb Bomb Stack [3]

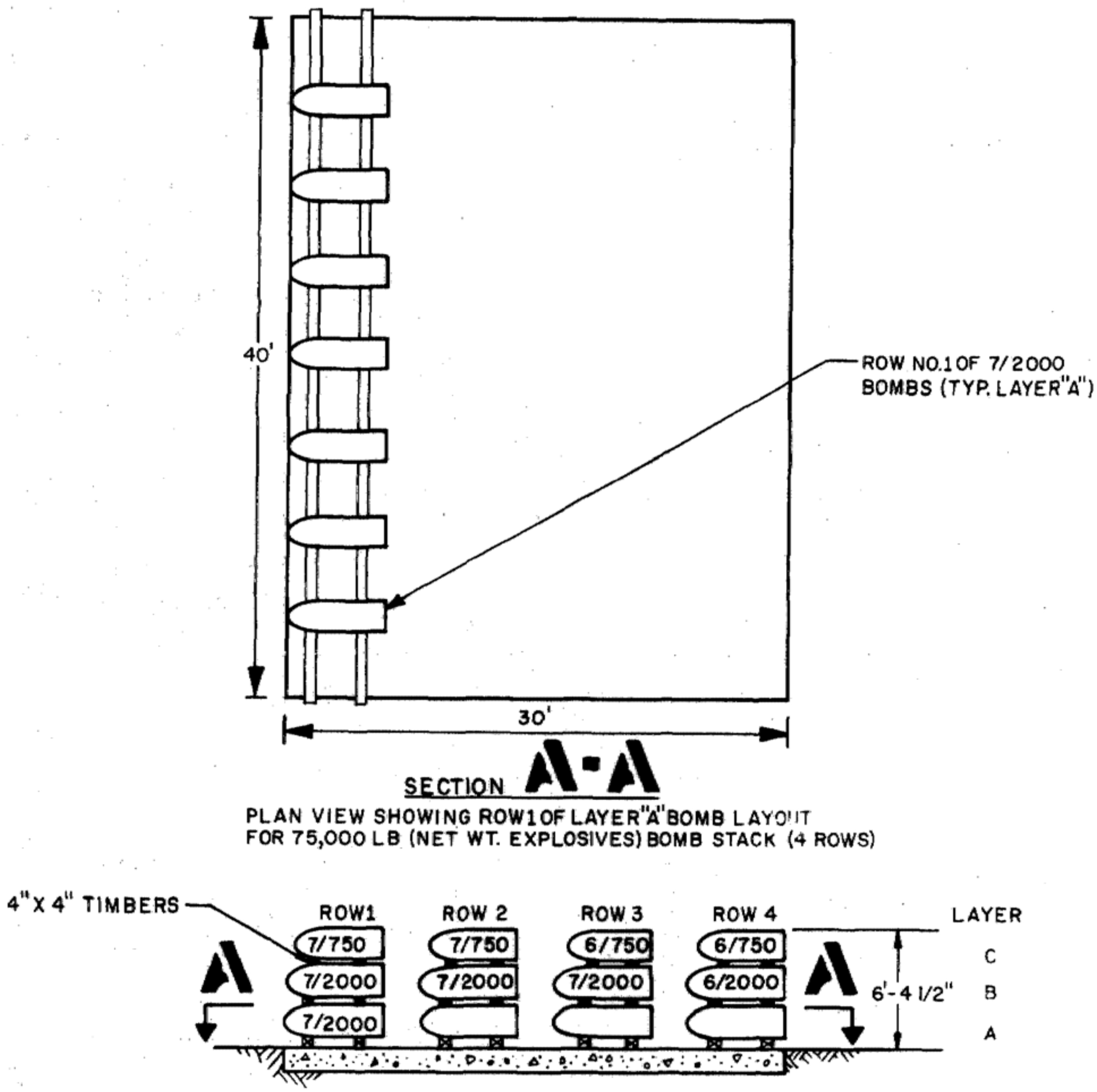
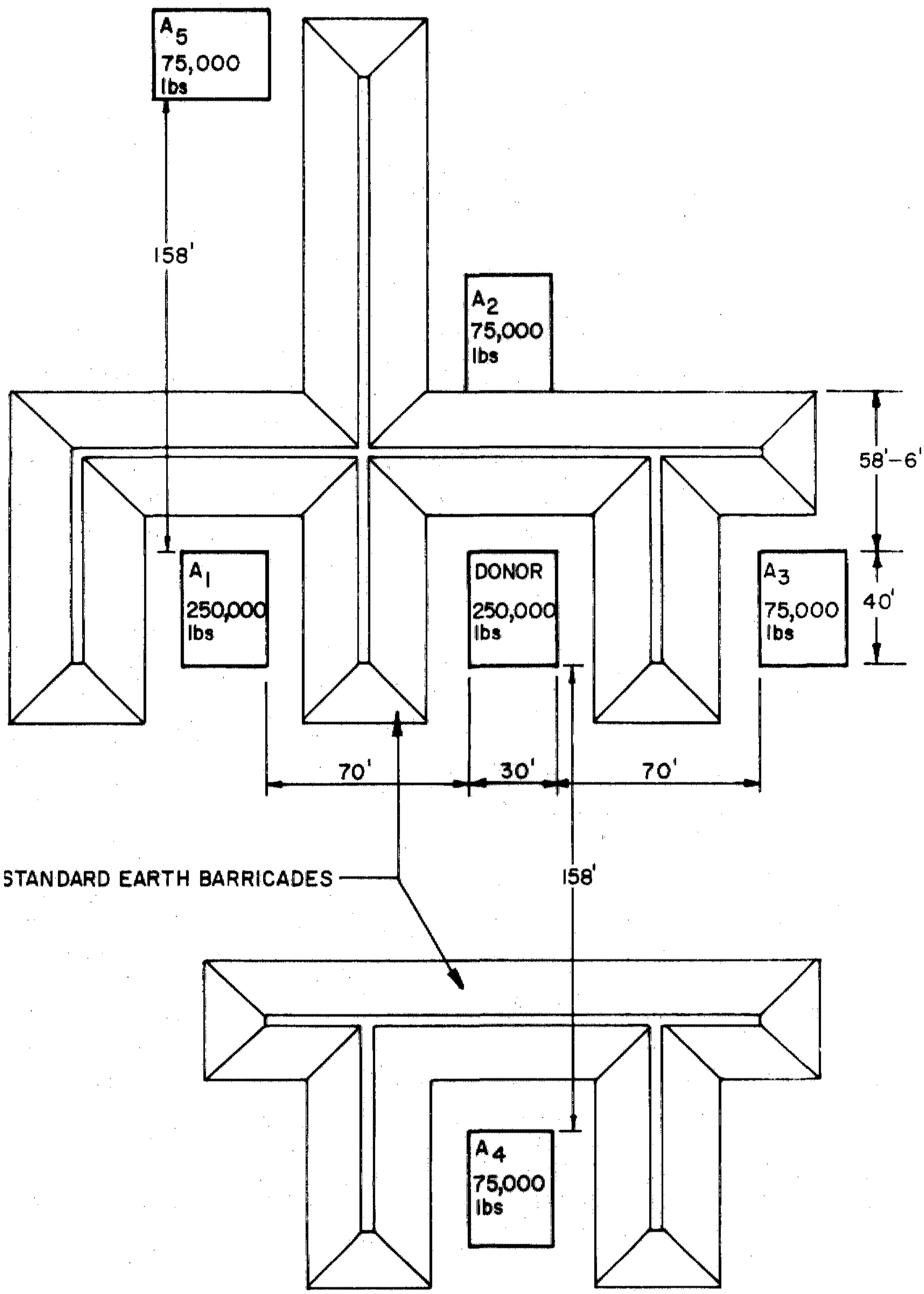


Figure 4 – Typical Bomb Arrangement for 75,000 lb Bomb Stack [3]



NOTES: DONOR, A_1, A_2, A_3 AND A_4 ARE ON REINFORCED CONCRETE. A_5 IS ON THE NATURAL GROUND SURFACE. ALL WEIGHTS ARE NET WT EXPLOSIVES.

Figure 5 – Test Configuration for Phase I [3]

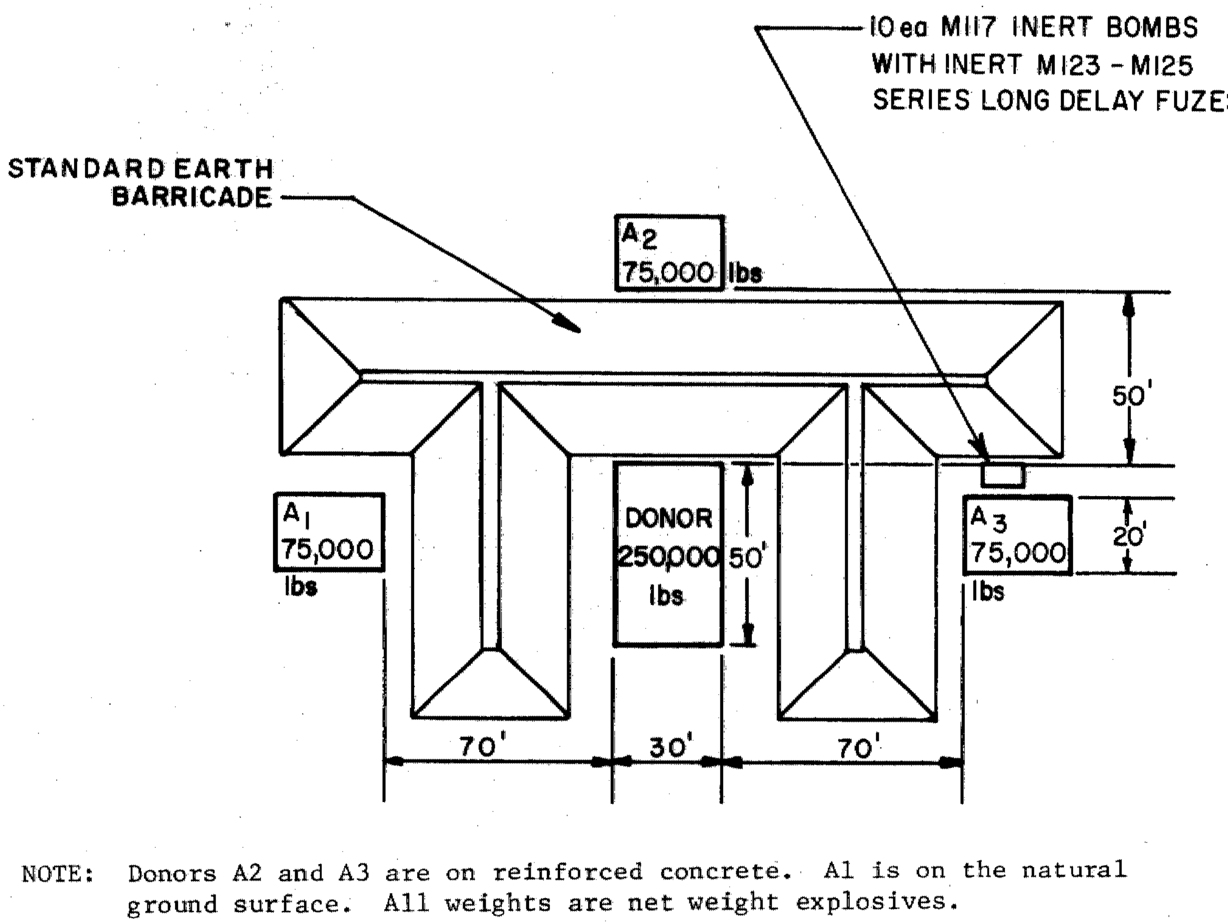


Figure 6 – Test Configuration for Phase II [3]

2.1.3 Conclusions From Big Papa Tests

For Phases I and II most of the primary fragments collected were less than 0.25 lbs and about 90% of these were found on the first two fragmentation areas (barricaded intraline distance and barricaded public highway/railway distance) in each direction. These fragments were small and projected over the barricade rather than through it. "Also, these small fragments probably would not cause as much damage to a structure at these distances as the overpressure resulting from a 250,000 lb detonation." [3]

The height of the barricades across the 30 ft side of the pad met the 2-degree theory but the height across the 40 ft side was slightly shorter than required to meet the 2-degrees. It was concluded that if the 2-degree rule was maintained, no greater fragment density than occurred in Phases I and II would be experienced.

The following conclusions were reached as a result of the Big Papa Tests (paraphrased):

a. A substantial reduction can be made in the current DoD barricaded aboveground intermagazine QD criteria for mass-detonating explosives in open storage.

b. Bombs located at K1.1 or less from the donor explosives will be covered with earth and unavailable for use until extensive uncovering operations are completed. Bombs at K2.5 separations will be readily accessible.

c. The minimum barricaded distance between single stacks of mass-detonating explosives stored in adjacent cells of a module could be based on a K factor of 1.1 with a high degree of confidence. However, some possibility of non-simultaneous propagation exists under some circumstances due to dunnage flammability and damaging fragments escaping over the barricade.

d. The modular concept is sound for large-quantity munitions storage.

e. Since no sympathetic detonations occurred in the test modules, the spacing between modules could be based on a K factor of 2.5 as related to the NEW in one cell rather than the NEW of the entire module.

f. The recommendation of 100,000 lbs per cell can be increased to 250,000 lbs provided that the spacing corresponding to a K factor of 1.1 is maintained.

g. Since no sympathetic detonations occurred, the number of cells per module (five originally recommended) may be considered arbitrary.

h. The vertical acceleration delivered to a bomb stack resting on the natural ground surface is about twice the magnitude of one standing on a concrete storage pad.

i. The frontal air pressure is consistently higher than the ground surface pressure at any given distance out from the detonation.

j. The standard earth barricade does affect the airblast in the immediate vicinity of the barricade but the disturbance dissipated rapidly as the blast front moved out from the detonation. The pressure at a given point on the ground beyond the tow of the barricade was the same as to be expected where no barricades are employed.

k. Since very few fragments of significance were found out to the barricaded highway/railway distance most damage to structures would probably result from airblast effects.

l. The Air Force “2-degree” theory for proper barricade height is sound.

m. The standard earth barricade provides excellent fragmentation protection for adjacent bomb stacks stored within a module as in Phases I and II.

n. Cell-to-cell propagation purely by airblast probably would not occur.

o. Stacks of bombs spaced at K1.1 would require considerable recovery effort if one of the stacks detonated, whereas stacks spaced at K2.5 would require very little recovery effort.

The remaining conclusions pertained to Phases III and IV and are not discussed here.

2.2 Changes to the Standards for Design of Barricades to Prevent Prompt Propagation

As a result of the Big Papa Tests, the DoD Ammunition and Explosives Safety Standards were changed to incorporate the 2-degree theory. The July 1974 DoD Ammunition and Explosives Safety Standards [4] changed the required barricade height from 3 ft above the top of the stacks to the new "2-degree" theory proposed by AFIAS-G2 which stated that a straight line drawn from the far edge of the top of a bomb at a 2-degree angle above the horizontal must at least pass below the 3-foot wide crest of the standard earth barricade. This is the standard still used by DoD and NATO for determining the height of a barricade between stacks of AE.

As seen in Figures 5 and 6, these tests were designed to test the modular storage cell concept. These tests were not designed to test the design of barricades for ammunition stacks at barricaded intermagazine distance (K6). Conclusions about the barricade design requirements for these configurations may not be valid for such ammunition storage configurations. However, the current DoD 6055.9-STD requirements for all barricades to prevent prompt propagation are based on this 2-degree theory.

3.0 Current Barricade Design Requirements

The requirements for the design of barricades to prevent prompt propagation are specified in paragraph C5.3.2.3 of DoD 6055.9-STD and its sub-paragraphs. These paragraphs are quoted below (Note: DoD 6055.9-STD, Fig C5.F3 is shown as Figure 7):

C5.3.2.3. Barricade Size and Orientation for Protection Against High-Speed, Low-Angle Fragments. The location, height, and length of a barricade shall be determined as follows:

C5.3.2.3.1. Location. The barricade may be placed anywhere between the PES and the ES. The location shall determine the barricade's required height and length.

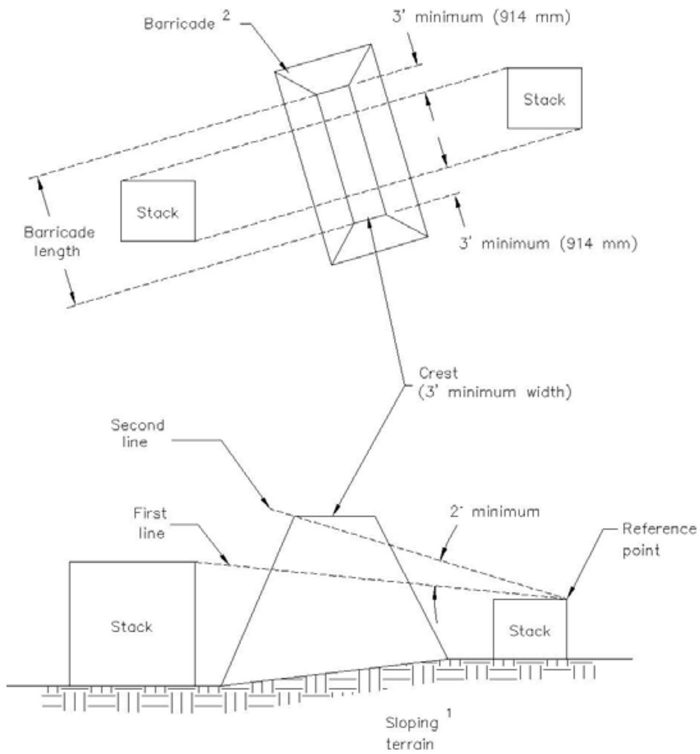
C5.3.2.3.2. Height. To determine the required barricade height:

C5.3.2.3.2.1. Establish a reference point at the top of the far edge of one of the two AE stacks between which the barricade is to be constructed. When both stacks are of equal height, the reference point may be established on either stack. If the tops of the two stacks are not of equal height (elevation), the reference point shall be on the top of the lower stack. (NOTE: To preclude building excessively high barricades, the barricade should be located as close as possible to the stack on which the reference point was established (see DoDD 6055.9-STD, Fig. C5.F3.))

C5.3.2.3.2.2. Draw a line from the reference point to the highest point of the other stack.

C5.3.2.3.2.3. Draw a second line from the reference point forming an angle of two degrees above the line.

C5.3.2.3.2. Length. The barricade's length shall be determined per Figure C5.F3.



Notes:

1. This illustration is for sloping terrain; however, a similar approach is used for level terrain.
2. Barricade must meet construction and siting criteria of section C5.3.

Figure 7 - Determination of Barricade Length and Height (DoD 6055.9-STD, Fig. C5.F3,)

3.1 Issues with Current Barricade Design Requirements

Just as the Air Force had issues with the land required for barricaded open storage in Southeast Asia in the 1960's, the Army is facing construction problems and real estate challenges as a result of the 2-degree rule for barricades currently required. One extreme case is a storage pad that is 720 ft x 125 ft storing 500,000 lbs NEW. This requires a barricade that is 36 ft tall in order to store 8 ft tall stacks. A more typical storage pad is 134 ft x 48 ft requiring a 14 ft tall barricade. One ammunition supply point containing 54 storage pads of various sizes required approximated 281,000 cubic yards of soil.

The 2-degree rule was originally proposed for storage modules not individual storage pads and it provided a reduction in the height of the barricade from the required 3 ft above the height of the stack. The cells in the storage module are considerably smaller than the size of typical individual storage pads. The tests that are the basis for the adoption of the 2-degree rule were designed to test storage modules not individual storage pads.

Considering the basis of the 2-degree rule and the cost of meeting this rule, the question becomes "Is this the necessary height to prevent prompt propagation between stacks of AE on individual storage pads sited at barricaded intermagazine distance (K6)?"

4.0 Analysis Approach

There are two components to the 2-degree barricade height requirement. The first is the establishment of a reference point and the second is the requirement that the height of the barricade be such that line 2-degrees above the line drawn through the reference point pass through the entire 3 ft crest of the barricade (see Figure 7). An analysis to determine the necessary height of a barricade to prevent prompt propagation must consider both of these elements.

The analytical approach used is outlined below.

a. Determine whether or not the reference point needs to be at the far edge of the stack.

b. One of the conclusions from the Big Papa Tests was that at a distance of K1.1 propagation was unlikely to occur due to overpressure. Individual storage pads with barricades are sited at K6 (barricaded intermagazine distance) and the purpose of barricades is to stop the low-angle, high velocity fragments so it is necessary to determine the critical velocity of fragments required to cause propagation.

c. If fragments with this critical velocity do not land on the AE stack on the adjacent pad, then they cannot cause propagation. Therefore, the next step is to complete trajectory analyses to determine the trajectories of fragments that may cause propagation.

d. In order for detonations to be considered simultaneous, they must occur within a short time of each other. This time is defined in paragraph C9.3.1.2.1 of DoD 6055.9-STD [1]. Therefore, the analysis includes determining the time at which any fragments with velocities above the critical velocity will strike the AE stack on the adjacent pad.

4.1 Location of Reference Point

Although no reference for the location of the reference point could be found, it is assumed that the location of the reference point was based on fragmentation from munitions in the top layer of the stack. This corresponds to the NATO AASTP 1 [5] method for calculating the hazardous fragment distance for stacks of munitions. For the hazardous fragment distance for a stack of munitions, this method considers the number of munitions on the face of the stack in the direction of interest and the number of munitions in the top layer of the stack (see DDESB Technical Paper 16 [6] for details). However, the hazardous fragment distance and the associated methodology is a personnel protection not a propagation prevention criterion. The assumption that fragments from munitions in the top layer of the stack should be used to design a barricade to prevent prompt propagation is examined below.

4.1.1 Fragmentation Distribution

The fragments from a single munition are propelled from the munition in a direction normal to the original surface of the munition. When a detonation of a stack of munitions occurs, there are interaction zones between the munitions (see Figure 8). These interaction zones affect the initial angle at which the fragments within these interaction zones are propelled away from the stack versus the initial angle at which fragments are propelled away from the detonation of a single munition.

The fragments from the munitions cases within the interior interaction zone do not affect the fragment exterior distribution, but are instead trapped in the interior area. The fragments from the munitions cases within the exterior interaction zones are propelled away from the stack at a higher velocity than the fragments from the areas not within an interaction zone. Depending upon the method of initiation, the initial angle of the fragments from the exterior interaction zone varies. When all munitions are detonated simultaneously, the fragments from the exterior interaction zones are propelled away from the stack normal to the face of the stack. When the detonation begins with a single munition and propagates through the stack, the fragments from the exterior interaction zones are propelled away from the stack at angles up to 30 degrees from the normal to the face of the stack. These effects have been well documented [7, 8, 9]. The fragments from the areas not affected by an interaction zone are propelled away from the stack in the same manner as fragments from a single munition (i.e., normal to the surface of the munition). The fragment launch angles shown bound the launch angles whether the munitions are stacked with their axes horizontal or vertical.

4.1.2 Fragments from Stacks and Barricades

Per DoD 6055.9-STD [1], C5.1.2.1, the purpose of a barricade between stacks of munitions is to prevent propagation between the stacks. If loss of assets is acceptable, then the goal is to prevent prompt propagation. DoD 6055.9-STD [1], C5.3.1.2. states, “To reduce the hazards from high-velocity, low-angle fragments, the barricade must be placed between the Potential Explosion Source (PES) and the Exposed Site (ES) so that the fragments of concern impact the barricade before the ES.” Figure 9 shows two stacks of munitions separated by a barricade designed per DoD 6055.9-STD [1], Fig. C5.F3.

Using the maximum weight fragment from a Mk 84 bomb as an extreme case, the fragment trajectories for fragments launched from the top of a stack at the angles discussed above (i.e., 30 degrees from vertical to vertical) are shown in Figure 10.

If the trajectories from Figure 10 are generated from fragments from the top rear of Stack A in Figure 9, some of these fragments may strike Stack B, but such fragments are high-angle fragments (see Fig. 11). DoD 6055.9-STD [1], C5.3.1.1., states, “barricades provide no protection against high-angle fragments or lobbed AE.” Therefore, these are not the fragments that the barricade is intended to defeat and the reference point for determining the height of the barricade should not be predicated on these fragments.

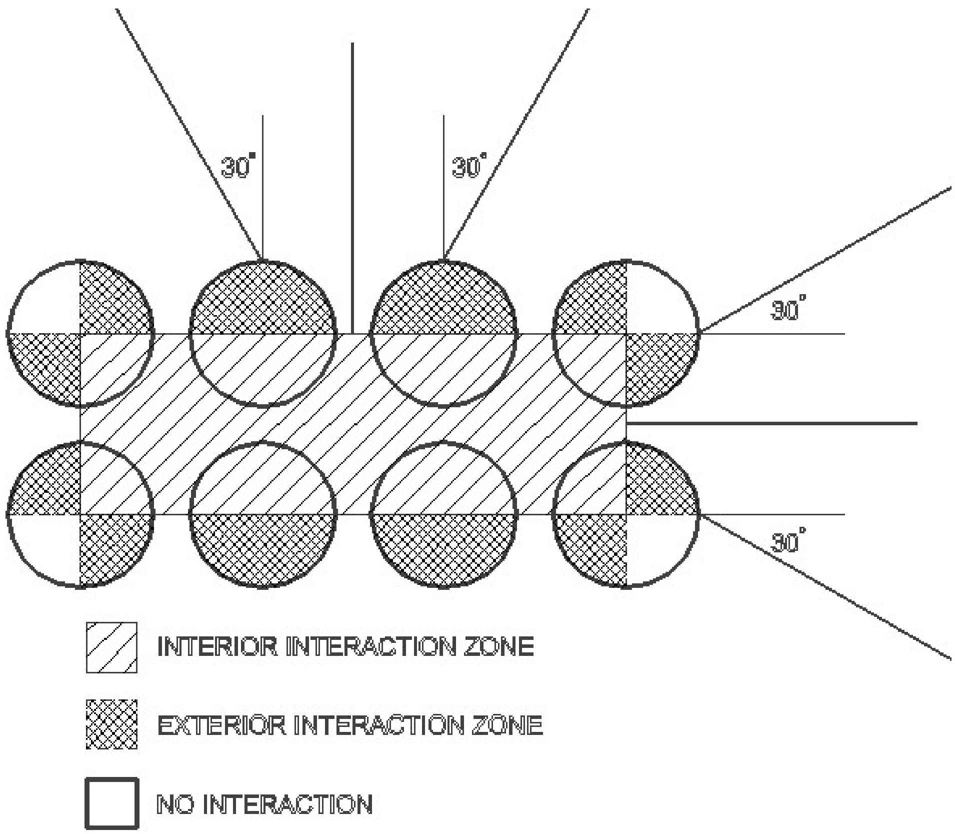


Figure 8 – Fragment Interaction Zones

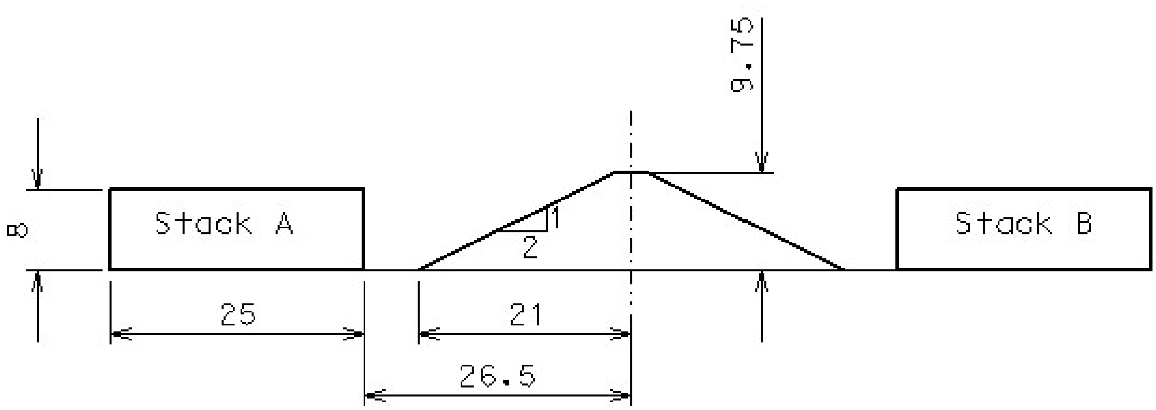


Figure 9 – Munition Stacks with Barricade Designed per DoD 6055.9-STD, Fig. C5.F3

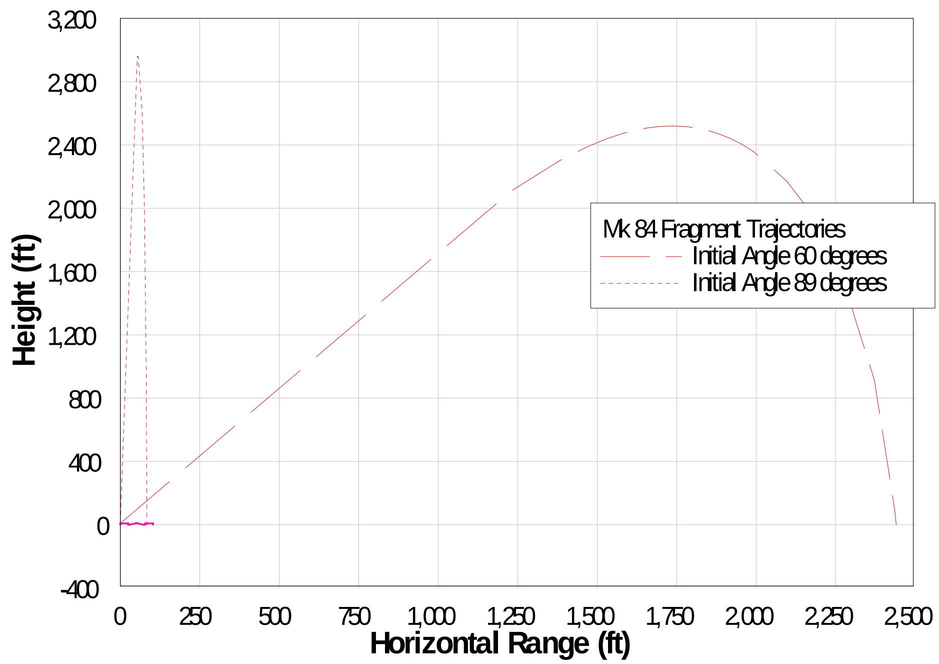


Figure 10 – MK 84 Fragment Trajectories

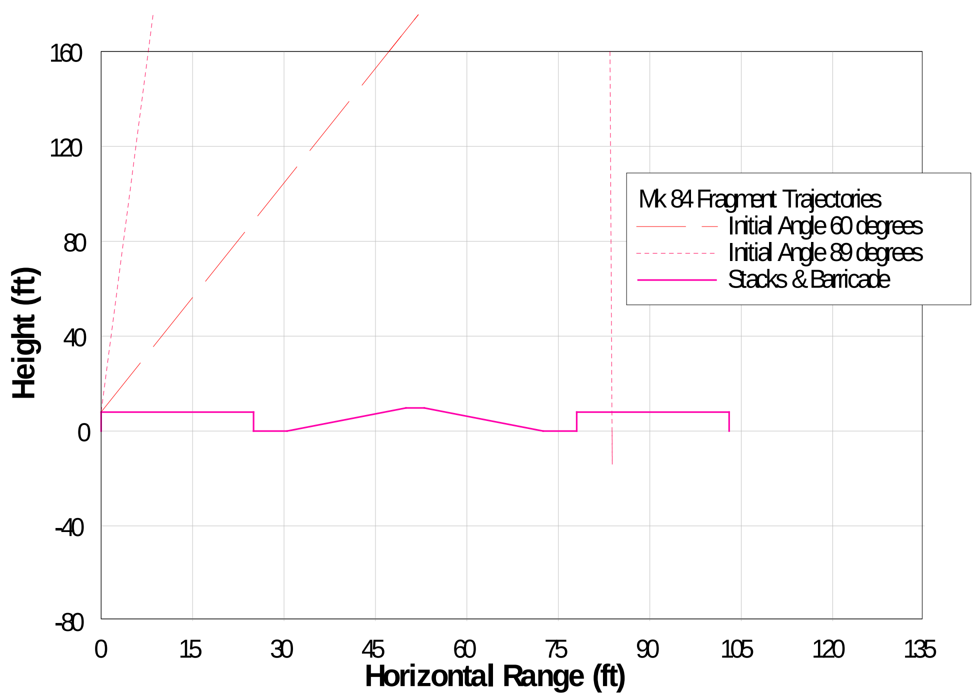


Figure 11 – Stacks and Barricade with MK 84 Fragment Trajectories

4.1.3 Location of Reference Point Conclusions

The fragments that are launched from the top of a stack of munitions are high angle fragments that cannot be defeated by a barricade. In fact, DoD 6055.9-STD [1] specifically states that barricades are not intended to defeat high-angle fragments or lobbed AE. Barricades are intended to defeat low-angle, high velocity fragments as per DoD 6055.9-STD [1]. Such low-angle fragments from a stack of munitions can only originate from the face of the stack that is facing the barricade (the near edge of the stack). Therefore, the reference point could be located at the near edge of the stack rather than the far edge as currently required.

However, since it is possible that a pad may not be completely covered by AE (especially a very large pad), the barricades must be designed to be effective no matter where on the pad the AE stack is located. The worst case occurs when a small stack of AE is located at one edge of a large pad. Therefore, it is advisable to locate the reference point on the top of the maximum height stack (usually a MILVAN or CONEX container height) at the far edge of the pad from the barricade.

4.2 Critical Velocity of Fragments

Naval Surface Warfare Center (NSWC) experiments have shown that the critical impact velocity required for shock induced explosive detonation can be sharply defined in a fairly small number of tests when fragment/target conditions are carefully controlled. The size, shape and velocity of the fragment will determine its ability to initiate the target explosive. [10, 11]

An experimental form, known as the Jacobs-Roslund Equation, adequately represents fragment response of explosives for a variety of fragment and target conditions. In the equation, the critical impact velocity for target detonation is related to explosive sensitivity, fragment size and shape, and target cover thickness as follows:

$$V_c = (A / d^{1/2})(1 + B)(1 + CT / d)$$

where V_c = critical impact velocity for target detonation (mm/μsec)
d = fragment critical dimension, e.g. diameter (mm)
T = target cover thickness (mm)
A = explosive sensitivity coefficient ($mm^{3/2}$/μsec)
B = fragment shape coefficient (dimensionless)
B = 0 for flat-end fragments
C = cover plate protection coefficient (dimensionless)

Coefficients for the Jacobs-Roslund Equation are experimentally established. These coefficients for a variety of explosives are shown in Table 1. The fragment impact explosive sensitivity coefficient, A, provides a means of ranking explosive sensitivity. Good correlation between "A" and "P_{50}" of the Large Scale Gap Test has been demonstrated when comparable explosive test samples are used. [10, 11]

Table 1 – Jacobs-Roslund Equation Coefficients [10, 11]

Explosive Type	Density (g/cm^3)	A (mm$^{3/2}$/μsec)	B - Hemispherical Fragment	C - Flat Fragment	C - Hemispherical Fragment
Comp B	1.71	3.06	0.91	1.70	0.56
H-6	1.74	3.36	0.94	1.65	0.54
HBX-1	1.76	3.76	0.99	1.56	0.51
PBX-9404	1.83	2.10	0.81	1.91	0.63
PBX(AF)-108	1.57	3.55	0.96	1.60	0.53
PBXC-117	1.74	3.65	0.98	1.58	0.52
PBXN-103	1.84	5.70	1.34	1.16	0.38
PBXN-109	1.66	4.00	1.02	1.51	0.50
PBXW-109 I	1.66	4.95	1.18	1.31	0.43
PBXW-113(II)	1.66	3.57	0.97	1.60	0.53
Tetryl	1.65	1.52	0.76	2.02	0.67

In order to determine the critical velocity of the fragments required to initiate propagation, the Jacobs-Roslund Equation was used. Examination of this equation shows that the critical velocity is inversely proportional to the size of the donor fragment. Although naturally occurring fragments are neither flat nor hemispherical, the coefficients for the hemispherical fragment were used to avoid being unduly conservative. Other conservative assumptions were made.

In order to determine the critical velocity for a representative sample of munitions including rockets, mines, grenades, mortars, projectiles and bombs, the munitions in the fragment characteristics database associated with DDESB TP 16 [6] were used. Neglecting the 16” Naval projectile and the U.S. Civil War munitions, the largest calculated fragment came from the MK 84 bomb. In accordance with DDESB TP 16, the fragment weight was increased by 33% to account for the effects of a stack of munitions rather than a single munition.

The munitions in the DDESB TP 16 database contain explosives not listed in Table 1. Since the Jacobs-Roslund sensitivity coefficient A shows good correlation to the P_{50} from the Large Scale Gap Test this value was used to determine the relative sensitivity of the explosives contained in these munitions and the Jacobs-Roslund coefficients for the next most sensitive explosive was used where these coefficients were not available (see Table 2). For explosives shown by the Large Scale Gap Test to be more sensitive than tetryl, the Jacobs-Roslund coefficients for tetryl were used.

The items in the DDESB TP 16 were analyzed to determine the critical velocity required to cause shock initiation by the calculated maximum weight fragment from a MK 84 bomb. One hundred thirteen (113) munition items including rockets, mines, grenades, mortars, projectiles and bombs were analyzed and the resulting critical velocities are 1114 ft/sec based on the maximum weight fragment.

Table 2 – Jacobs-Roslund Coefficients Used in Critical Velocity Analysis

Explosive Type	NSWC Large Scale Gap (n/cm)	A (mm$^{3/2}$/msec)	Use Jacobs-Roslund Coef. For Expl. Type	LANL Gap (mm)
PBXN-103	89	5.7		
Tritonal* (80/20)	100		PBXW-113(I)	22.1
HBX-1	154	3.76		
PBXW-113(II)	154	3.57		
Explosive D*	156		PBX(AF)-108	42.98
Amatol* (60/40)	162		PBXC-117	
PBXC-117	162	3.65		
PBX(AF)-108	175	3.55		27.2
TNT*	175		PBX(AF)-108	46.43
Cyclotol 75/25	182		H-6	43.15
Cyclotol 70/30*	182		H-6	
H-6*	197	3.36		
Comp B*	201	3.06		44.58
Octol* (65/35)	214		PBX-9404	
RDX/wax (91/9)	217		PBX-9404	
PBXN-109*	225		PBX-9404	
Comp A-3*	230		PBX-9404	54.51
Octol (60/40)*	232		PBX-9404	
PBX-9404	235	2.1		59.21
Tetryl*	238	1.52		60.6
Octol (75/25)*[A]	249		Tetryl	49.45
Pentolite*	272		Tetryl	64.74
RDX*	323		Tetryl	70.2
HMX*			Tetryl	70.68
Black Powder*			PBX(AF)-108	
Comp A-5*			Tetryl	
Tetrytol* (75/25 Tetryl/TNT)			Tetryl	

*Types of explosives used in munition items listed in DDESB TP 16 database.
[A]References for Gap Test results are IHTR 2597 [12, 13, 14]

4.3 Trajectory Analyses

A series of trajectory analyses were completed using several different AE stack configurations. For the trajectory analyses the calculated maximum weight fragment from the MK 84 bomb was again used. The weight was increased by a factor of 33% in accordance with DDESB TP 16 [6] to account for multiple munitions and the resulting weight was rounded up to 3 lbs for ease of calculation. Initial velocities ranging from 1200 ft/sec to 8500 ft/sec were used. Fragment launch angles above 2-degrees were not considered (except where noted) since such angles would not be stopped by barricades designed in accordance with the current requirements.

Distance between the pads for each model was based on the barricaded intermagazine distance (K6). All barricades were standard earth barricades with 2-to-1 slopes on each side and 3 ft thick crests. The distance between the edge of the pad and the toe of the barricade was assumed to be 10 ft. Each donor pad was assumed to have munitions only along the far edge of the pad away from the barricade. Each acceptor pad was assumed to be full of munitions. Each munition stack, both donor and acceptor, was assumed to be 8 ft tall. The top of the stacks were assumed to be level. The barricade for Models 1 through 8, 11, and 12 were 9 ft tall, the barricade for Model 13 was 8 ft 9 in tall, and the barricade for Models 9 and 10 were designed in accordance with the current requirements. Models 1 through 10 and 13 had only one barricade located at the acceptor stack. Models 11 and 12 had two barricades, one at each stack. Figure 12 shows the general layout of the models used (only Models 11 and 12 had barricades around the donor pad) and Table 3 shows the dimensions used for each model.

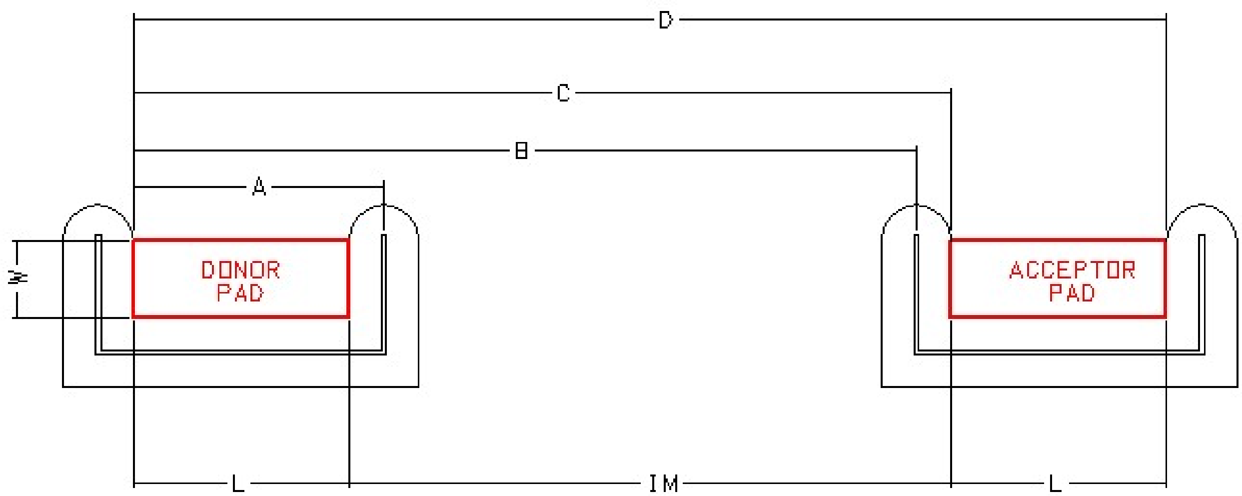


Figure 12 – General Model Layout

The results of these trajectory analyses are shown in Appendix A. These results were examined to determine:

1) if the fragments that went over the barricade struck the stack on the adjacent pad,

2) if the fragments that struck the acceptor stack struck with a velocity greater than the critical velocity of 1114 ft/sec, and

3) if the fragments struck at a time less than that required for any sympathetic detonation to be considered simultaneous (prompt). The time used to determine if any sympathetic detonation would be considered simultaneous was calculated, in accordance with paragraph C9.3.1.2.1 of DoD 6055.9-STD [1], by $5.6W^{1/3}$ where W is the maximum total NEW for a pad.

Table 3 – Model Dimensions

Model No.	No. of Barricades	Height of Barricade(s) (ft)	Length (L) of Pads (ft)	Width (W) of Pads (ft)	NEW Limit (lbs)	Distance (ft)				
						Barricaded IM (K6)	A	B	C	D
1	1	9	100	50	14,000	145	NA	217	245	345
2	1	9	134	48	14,000	145	NA	251	279	413
3	1	9	100	50	50,000	221	NA	293	321	421
4	1	9	134	48	50,000	221	NA	327	355	489
5	1	9	134	48	125,000	300	NA	406	434	568
6	1	9	200	50	125,000	300	NA	472	500	700
7	1	9	400	50	500,000	476	NA	848	876	1276
8	1	9	720	125	500,000	476	NA	1168	1196	1916
9	1	37	400	50	500,000	476	NA	792	876	1276
10	1	47	720	125	500,000	476	NA	1092	1196	1916
11	2	9	400	50	500,000	476	428	848	876	1276
12	2	9	720	125	500,000	476	748	1168	1196	1916
13	1	8.75	720	125	500,000	476	NA	1168	1196	1916

Trajectory analyses were conducted for combinations of 5 different pad sizes and 4 NEW limits with a fragment weight of 3 lbs and a variety of initial fragment velocities from 1200 ft/sec to 8500 ft/sec (see Appendix A). The pads were spaced at barricaded intermagazine distance (K6) based on the NEW limit. The worst case configuration (donor stack at far edge of long side of pad with barricade at the acceptor stack) was analyzed for each combination.

Examination of the results shows that the only cases (Models 7 and 8) in which fragments strike the acceptor stack with a velocity higher than the critical velocity are large pads with large NEW limits. These cases were analyzed using a barricade at the acceptor stack designed in accordance with the current 2-degree requirements for comparison (Models 9 and 10). These two cases were also analyzed with a barricade at the edge of the donor pad as well as at the acceptor pad (Models 11 and 12).

Although Models 11 and 12 show that the 3 lb donor fragment may strike the acceptor stack with a velocity higher than critical velocity, the time at which this fragment strikes is later than the time at which mass detonations of both 500,000 lb stacks would be considered simultaneous. Additionally, if the donor stack contains munitions only along the far edge of the pad, the donor stack could not contain 500,000 lbs so the maximum time separation for detonations to be considered simultaneous would be larger than shown in Appendix A. Also, if the donor stack contains munitions only along the far edge of the pad, the distance between the donor stack and the acceptor stack would be greater than unbarricaded intermagazine distance (K11).

Model 13 was the result of a series of trajectory analyses to determine the required height of the barricade above line-of-sight. The height of the barricade for the largest (worst case) pad was varied in 3-inch increments from 8 ft (line-of-sight) to 9 ft. This series of trajectory analyses showed that an 8 ft 9 in barricade was required so that the fragments striking the top of the acceptor stack struck at a time later than the time at which mass detonations of both 500,000 lb stacks would be considered simultaneous.

As the trajectory analyses show, the striking time of the fragments on the adjacent acceptor pad is later than the time at which mass detonations of both donor and acceptor stacks would be considered simultaneous. Other acceptor pads will be further from the donor stack than the adjacent one so the striking time of the fragments on these pads will be even later. Therefore, if these fragments strike with enough velocity to cause propagation, the detonations will not be simultaneous (prompt).

5.0 Conclusions

Conservative assumptions have been made throughout the analyses described above including:

1) use of the maximum calculated fragment weight from the list of munitions in the DDESB TP 16,

2) calculation of this maximum weight fragment using a 1.2 safety factor on the explosive weight in the munition,

3) use of Jacobs-Roslund coefficients for a more shock sensitive explosive where the coefficients were not available,

4) increase of the maximum calculated fragment weight by a factor of 1.33 to account for detonation of multiple munitions,

5) increase of this fragment weight to 3 lbs for ease of calculation,

6) assumption that donor stack contains munitions only at the far edge of the donor pad,

7) barricade only at the acceptor pad (except in Models 11 and 12), and

8) munitions are in the open (no boxes, containers, CONEX, etc.).

Application of the Jacobs-Roslund Equation to a wide variety of munitions including rockets, mines, grenades, mortars, projectiles and bombs yielded a minimum critical velocity which may cause propagation of 1114 ft/sec.

Examination of the results of the trajectory analyses of Models 1 – 8 show that Model 8 is the worst case. Therefore, the height of the barricade in Model 8 was varied from 8 ft (line-of-sight) to 9 ft in 3-inch increments to determine the required height of the barricade to prevent propagation. Model 13 shows that a barricade that is 9-inches above line-of-sight prevents fragments with a velocity greater than the critical velocity from striking the top of the acceptor stack at a time less than the time at which propagation would be considered prompt (time < $5.6W^{1/3}$).

A barricade height of 9 ft corresponding to line-of-sight (8 ft) plus 1 ft (which will also provide a safety factor against construction inaccuracies and erosion) was applied to a variety of pad sizes and NEW limits combinations. Trajectory analyses showed that in most cases, the donor fragment will not strike the acceptor stack with a velocity greater than this critical velocity. In the cases where the striking velocity did exceed this critical velocity, the time at which the fragment struck the acceptor stack exceeded the time at which the two detonations would be considered simultaneous.

A barricade height of 9-inches above line-of-sight between AE stacks is sufficient to prevent prompt propagation due to fragmentation between the stacks however due to construction realities 1 ft above line-of-sight is recommended. In most cases, such a barricade is sufficient to prevent propagation due to fragmentation. However, for large pads with large NEW limits such a barricade should not be relied upon for asset preservation.

Thus for Q-D siting purposes the individual open storage pad NEW limits may be used provided the following conditions are met.

1) The pads are spaced at intermagazine distance.

2) When the pads are spaced at barricaded intermagazine distance,

a. the reference point is located at the far edge of the pad furthest from the barricade,

b. the barricade height is at least line-of-sight plus 9-inches however due to construction realities 1 ft above line-of-sight is recommended, and

c. the barricade length meets the current barricade length requirements.

6.0 Recommended Changes to Barricade Design Requirements

It is recommended that the requirements for the height of barricades to prevent prompt propagation be changed to reflect the results of this study. Although only fragments from the face of the donor stack facing the acceptor stack need be considered, because a stack of AE may not completely fill a pad and may be anywhere on the pad, the reference point location should remain at the top far edge of the donor stack. However, the height of the barricade does not need to be 2-degrees above line-of-sight from this reference point. Applying 1 ft above the line-of-sight from this reference point in order to account for construction inaccuracies and erosion is sufficient. The proposed text and accompanying figure is shown below.

C5.3.2.3. Barricade Size and Orientation to Prevent Prompt Propagation Due to Low-Angle, High-Velocity Fragments. The location, height, and length of a barricade to prevent prompt propagation due to low-angle, high-velocity fragments shall be determined as follows:

C5.3.2.3.1. Location. The barricade may be placed anywhere between the PES and the ES. The location affects the barricade's required height and length.

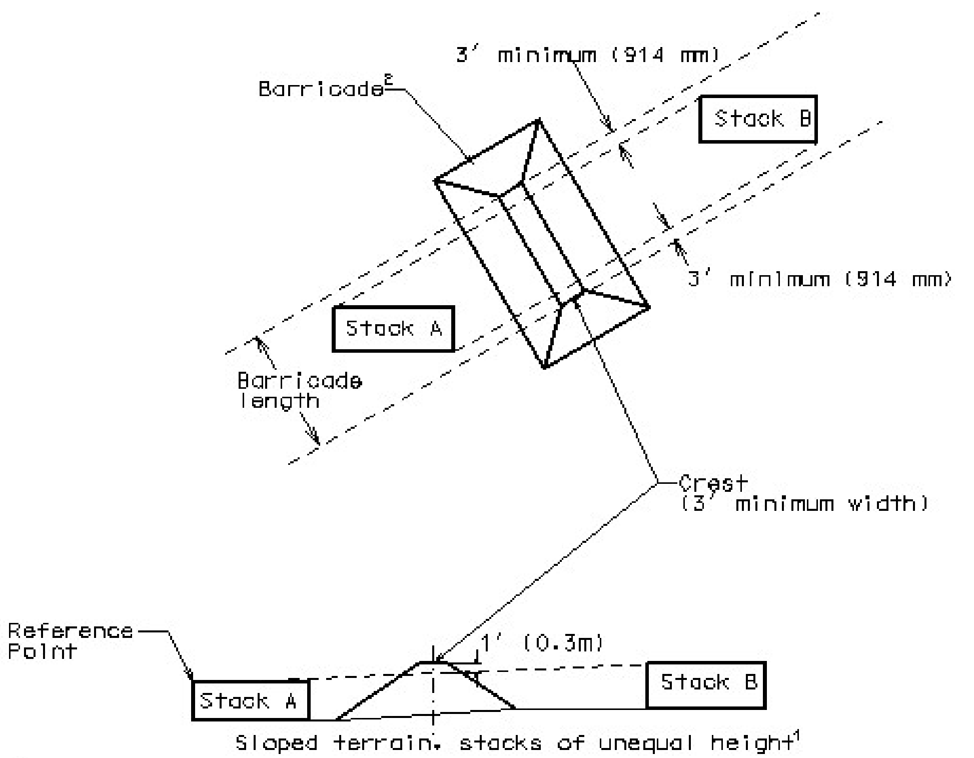
C5.3.2.3.2. Height. To determine the required barricade height:

C5.3.2.3.2.1. Establish a reference point at the top far edge of one of the two AE stacks between which the barricade is to be constructed. When both stacks are of equal height, the reference point may be established on either stack. If the tops of the two stacks are not of equal height (elevation), the reference point shall be on the top of the lower stack.

C5.3.2.3.2.2. Draw a line from the reference point to the highest point of the other stack (line-of-sight).

C5.3.2.3.2.3. The barricade's height shall be such that the entire width of the barricade crest shall be 1 ft (0.3m) above this line.

C5.3.2.3.3. Length. The barricade's length shall be determined per Figure C5.F3.



Notes:
1. This illustration is for sloped terrain, stacks of unequal height; however, a similar approach is used for level terrain, stacks of equal height.
2. Barricade must meet construction and siting criteria of section C5.3.

Proposed New Figure C5.F3. Determination of Barricade Length and Height (see subparagraph C5.3.2.3)

7.0 Example

Figure 13 shows four storage pads from an Ammunition Supply Point (ASP) at a location outside the continental United States (OCONUS). The stacks are a maximum of 8 ft tall, and the base elevation of each pad is approximately the same. The barricades are earthen berms requiring a 2 to 1 slope on the sides. Using the current design requirements and allowing room for the required slope of the berm, the required height of the barricade between the left and the right columns of pads is 13.6 ft and encumbers 58 ft of real estate in this direction. The required height of the barricade between the top and bottom rows of pads is 10.4 ft and encumbers 45 ft of real estate in this direction. Due to construction realities, this berm will usually be constructed the same height (13.6 ft) on all three sides of the pad. Each berm requires approximately 5,200 cubic yards of soil. This particular ASP contains 54 storage pads of various sizes (approximately 281,000 cubic yards of soil).

If the proposed barricade requirements are used, 9 ft barricades are required. This encumbers 39 ft of real estate around 3 sides of each pad and requiring approximately 2866 cubic yards of soil for each pad for a total of approximately 154,764 cubic yards of soil. This is 55% of the amount of soil required for the berms using the current requirements.

Because the barricade footprints are reduced there is a possible reduction in overall real estate required with accompanying savings in fencing, intrusion detection, etc. All of these benefits are realized without any increased risk of propagation between stacks of munitions.

Table 4 – Comparison of Berm Height/Size

Barricade Design Requirements	Required Height of Berm (ft)	Width of Base of Berm (ft)	Approx. Soil/ Berm (yd^3)	Approx. Total Soil (yd^3)
Current	13.6	58	5,200	281,000
Proposed	9	39	2866	154,764

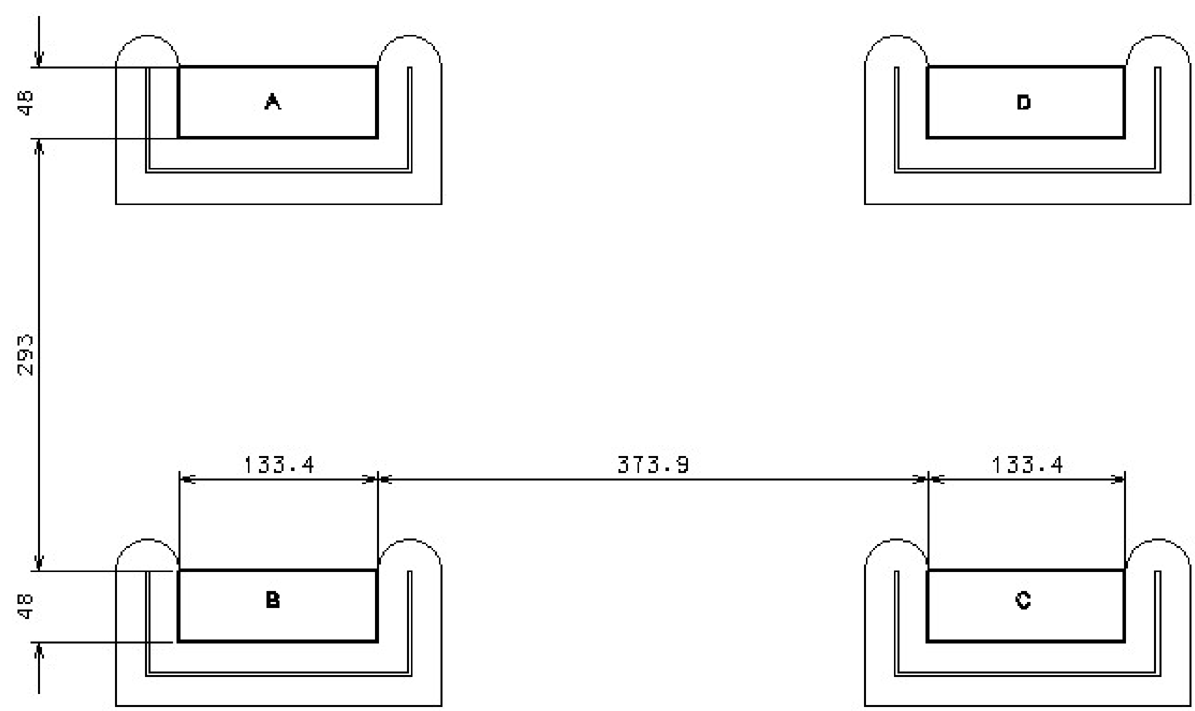


Figure 13 – Storage Pads at Ammunition Supply Point

8.0 References

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[14] Montesi, L., Burrows, K., Beyard, M., Gillis, A., IHTR 2597, “Large Scale Gap Test Sensitivity of Explosives: Compilation of Test Data, Volume III – Experimental Cast Cure Explosives”, Indian Head Division Naval Surface Warfare Center, 24 April 2006.

Appendix A
Trajectory Analyses Results

Model 1 Pad Size 100 x 50 NEW = 14,000 lbs
5.6 $W^{1/3}$ = 134.968

Initial Velocity (ft/sec)	Initial Angle of Frag Going Over Barrier (deg)	Horizontal Range (ft)	Striking Velocity (ft/sec)	Time (ms)
1200	0.43	841	585	1050
1300	0.41	884	598	1058
1400	0.39	924	610	1064
1500	0.37	963	621	1068
1600	0.36	1005	629	1079
1700	0.35	1046	637	1089
1800	0.34	1085	644	1097
1900	0.33	1123	650	1105
2000	0.33	1167	653	1121
2500	0.31	1355	669	1172
3500	0.29	1674	681	1256
4500	0.28	1932	680	1322
5500	0.28	2152	673	1384
6500	0.28	2340	666	1434
7500	0.28	2502	659	1476
8500	0.27	2632	659	1492

Will Strike Top of Adjacent Stack
Striking Velocity > 1114 fps
Time of Arrival > 135 ms

Conclusions:
No fragments < 2-deg initial angle will strike the top of the stack.

Model 2 Pad Size 134 x 48 NEW = 14,000 lbs
5.6 $W^{1/3}$ = 134.968

Initial Velocity (ft/sec)	Initial Angle of Frag Going Over Barrier (deg)	Horizontal Range (ft)	Striking Velocity (ft/sec)	Time (ms)
1200	0.43	841	585	1050
1300	0.4	879	600	1050
1400	0.38	919	612	1056
1500	0.36	958	623	1060
2200	0.29	1224	672	1110
2700	0.27	1397	688	1150
3200	0.26	1555	695	1189
3700	0.25	1693	700	1218
4200	0.25	1828	699	1256
4700	0.25	1950	696	1289
5200	0.24	2049	699	1302
5700	0.24	2146	696	1327
6200	0.24	2239	693	1350
6700	0.24	2326	690	1371
7200	0.24	2407	687	1391
7700	0.24	2482	684	1408
8200	0.24	2553	681	1425
8700	0.24	2620	678	1440

Will Strike Top of Adjacent Stack
Striking Velocity > 1114 fps
Time of Arrival > 135 ms

Conclusions:
No fragments < 2-deg initial angle will strike the top of the stack.

Model 3 Pad Size 100 x 50 NEW = 50,000 lbs

5.6 $W^{1/3}$ = 206.3058

Initial Velocity (ft/sec)	Initial Angle of Frag Going Over Barrier (deg)	Horizontal Range (ft)	Striking Velocity (ft/sec)	Time (ms)
1200	0.43	841	585	1050
1300	0.4	879	600	1050
1400	0.37	915	614	1048
1500	0.35	953	626	1052
1600	0.33	989	637	1054
1700	0.32	1029	645	1063
1800	0.3	1062	655	1061
1900	0.29	1099	662	1067
2000	0.28	1135	669	1073
2500	0.25	1310	693	1105
3000	0.24	1473	704	1145
3500	0.23	1617	711	1175
4000	0.22	1744	717	1198
4500	0.22	1870	715	1230
5000	0.21	1971	720	1242
5500	0.21	2074	717	1267
6000	0.21	2170	715	1289
6500	0.21	2258	712	1309
7000	0.21	2337	709	1327
7500	0.21	2413	706	1344
8000	0.21	2485	704	1360
8500	0.21	2553	701	1374

Will Strike Top of Adjacent Stack

Striking Velocity > 1114 fps

Time of Arrival > 206 ms

Conclusions:
No fragments < 2-deg initial angle will strike the top of the stack.

Model 4 Pad Size 134 x 48 NEW = 50,000 lbs

5.6 $W^{1/3}$ = 206.3058

Initial Velocity (ft/sec)	Initial Angle of Frag Going Over Barrier (deg)	Horizontal Range (ft)	Striking Velocity (ft/sec)	Time (ms)
1200	0.45	850	581	1064
1300	0.41	884	598	1058
1400	0.38	919	612	1056
1500	0.36	958	623	1060
1600	0.33	989	637	1054
1700	0.31	1023	648	1054
1800	0.3	1062	655	1061
1900	0.29	1099	662	1067
2000	0.28	1135	669	1073
2500	0.24	1302	698	1094
3000	0.22	1456	714	1120
3500	0.21	1597	722	1148
4000	0.2	1723	728	1169
4500	0.2	1847	728	1199
5000	0.2	1959	726	1226
5500	0.19	2049	731	1233
6000	0.16	2144	729	1254
6500	0.19	2231	727	1273
7000	0.19	2312	724	1290
7500	0.19	2388	722	1306
8000	0.19	2460	719	1320
8500	0.19	2527	717	1334

Will Strike Top of Adjacent Stack

Striking Velocity > 1114 fps

Time of Arrival > 206 ms

Conclusions:
No fragments < 2-deg initial angle will strike the top of the stack.

Model 5 Pad Size 134 x 48 NEW = 125,000 lbs
5.6 $W^{1/3}$ = 280

Initial Velocity (ft/sec)	Initial Angle of Frag Going Over Barrier (deg)	Horizontal Range (ft)	Striking Velocity (ft/sec)	Time (ms)
1200	0.5	533	741	580
1300	0.45	546	776	560
1400	0.41	562	807	545
1500	0.38	968	619	1076
1600	0.35	1000	632	1071
1700	0.32	1029	645	1063
1800	0.3	1062	655	1061
1900	0.29	1099	662	1067
2000	0.27	1128	673	1063
2500	0.23	1294	702	1083
3000	0.2	1438	724	1095
3500	0.19	1577	733	1121
4000	0.18	1701	741	1139
4500	0.17	1812	748	1152
5000	0.17	1922	747	1177
5500	0.16	2011	753	1181
6000	0.16	2103	752	1200
6500	0.16	2190	750	1218
7000	0.16	2270	748	1233
7500	0.16	2345	746	1248
8000	0.15	2400	753	1241
8500	0.15	2467	751	1253

Will Strike Top of Adjacent Stack
Striking Velocity > 1114 fps
Time of Arrival > 280 ms

Conclusions:
Although fragments < 2-deg initial angle will strike the top of the stack, none have a high enough velocity to cause propagation.

Model 6 Pad Size 200 x 50 NEW = 125,000 lbs
5.6 $W^{1/3}$ = 280

Initial Velocity (ft/sec)	Initial Angle of Frag Going Over Barrier (deg)	Horizontal Range (ft)	Striking Velocity (ft/sec)	Time (ms)
1200	0.55	571	720	632
1300	0.5	588	751	615
1400	0.45	599	784	592
1500	0.41	613	814	575
1600	0.37	622	847	552
1700	0.35	648	868	551
1800	0.32	658	901	533
1900	0.3	677	927	525
2000	0.28	693	956	515
2500	0.23	1294	702	1083
3000	0.19	1429	729	1083
3500	0.18	1567	739	1107
4000	0.16	1679	754	1110
4500	0.16	1800	755	1137
5000	0.15	1897	762	1144
5500	0.15	1997	761	1164
6000	0.14	2076	768	1164
6500	0.14	2161	767	1180
7000	0.14	2241	765	1195
7500	0.14	2315	764	1208
8000	0.14	2385	762	1221
8500	0.14	2451	760	1232

Will Strike Top of Adjacent Stack
Striking Velocity > 1114 fps
Time of Arrival > 280 ms

Conclusions:
Although fragments < 2-deg initial angle will strike the top of the stack, none have a high enough velocity to cause propagation.

Model 7 Pad Size 400 x 50 NEW = 500,000 lbs
$5.6\ W^{1/3}$ = 444.4723

Initial Velocity (ft/sec)	Initial Angle of Frag Going Over Barrier (deg)	Horizontal Range (ft)	Striking Velocity (ft/sec)	Time (ms)
1200	1.06	885	564	1127
1300	0.94	888	594	1067
1400	0.84	894	623	1016
1500	0.76	904	649	976
1600	0.68	906	679	927
1700	0.62	916	704	894
1800	0.56	919	732	854
1900	0.51	924	759	820
2000	0.47	934	782	794
2500	0.32	972	907	677
3000	0.24	1020	1028	604
3500	0.2	1094	1118	576
4000	0.17	1158	1209	550
4500	0.15	1226	1284	535
5000	0.13	1268	1382	508
5500	0.12	1956	786	1111
6000	0.11	2032	794	1109
6500	0.11	2116	794	1123
7000	0.1	2178	803	1116
7500	0.1	2251	802	1128
8000	0.1	2319	802	1138
8500	0.09	2366	812	1126

Will Strike Top of Adjacent Stack
Striking Velocity > 1114 fps
Time of Arrival > 444 ms

Conclusions:
Some fragments < 2-deg initial angle will strike the top of the stack. Even if a large enough fragment struck the top of the stack, the time of arrival is late enough that the two detonations would not be simultaneous. Therefore, the NEW for Q-D would be one stack (i.e. 500,000 lbs NEW).

Model 8 Pad Size 720 x 125 NEW = 500,000 lbs
$5.6\ W^{1/3}$ = 444.4723

Initial Velocity (ft/sec)	Initial Angle of Frag Going Over Barrier (deg)	Horizontal Range (ft)	Striking Velocity (ft/sec)	Time (ms)
1200	1.77	1306	409	2016
1300	1.58	1321	427	1939
1400	1.4	1333	446	1858
1500	1.26	1195	518	1481
1600	1.13	1196	543	1407
1700	1.03	1203	564	1351
1800	0.93	1203	588	1287
1900	0.85	1208	610	1237
2000	0.78	1213	631	1191
2500	0.52	1230	738	992
3000	0.37	1248	839	851
3500	0.28	1274	937	751
4000	0.23	1322	1020	697
4500	0.19	1356	1115	644
5000	0.16	1385	1214	598
5500	0.14	1423	1299	568
6000	0.13	1485	1341	563
6500	0.12	1535	1390	552
7000	0.11	1574	1449	537
7500	0.1	1602	1520	517
8000	0.1	1681	1500	534
8500	0.09	1693	1586	508

Will Strike Top of Adjacent Stack
Striking Velocity > 1114 fps
Time of Arrival > 444 ms

Conclusions:
Some fragments < 2-deg initial angle will strike the top of the stack. Even if a large enough fragment struck the top of the stack, the time of arrival is late enough that the two detonations would not be simultaneous. Therefore, the NEW for Q-D would be one stack (i.e. 500,000 lbs NEW).

Model 9 Pad Size 400 x 50 NEW = 500,000 lbs
$5.6\ W^{1/3}$ = 444.4723 2-deg barricade

Initial Velocity (ft/sec)	Initial Angle of Frag Going Over Barrier (deg)	Horizontal Range (ft)	Striking Velocity (ft/sec)	Time (ms)
1500	2.75	1800	334	2942
2000	2.45	2051	340	3027
2500	2.35	2286	336	3174
3000	2.25	2473	334	3263
3500	2.25	2661	326	3410
4000	2.2	2813	323	3488
4500	2.2	2962	318	3595
5000	2.15	3074	316	3634
5500	2.15	3189	312	3711
6000	2.15	3294	309	3780
6500	2.15	3390	306	3842
7000	2.15	3480	303	3899
7500	2.15	3563	300	3950
8000	2.15	3640	298	3998
8500	2.15	3714	296	4042

Will Strike Top of Adjacent Stack
Striking Velocity > 1114 fps
Time of Arrival > 444 ms

Conclusions:
No fragments < 2-deg initial angle will strike the top of the stack.

Model 10 Pad Size 720 x 125 NEW = 500,000 lbs
$5.6\ W^{1/3}$ = 444.4723 2-deg barricade

Initial Velocity (ft/sec)	Initial Angle of Frag Going Over Barrier (deg)	Horizontal Range (ft)	Striking Velocity (ft/sec)	Time (ms)
2000	2.7	2101	324	3208
2500	2.45	2320	329	3260
3000	2.35	2508	327	3353
3500	2.25	2667	326	3409
4000	2.2	2818	323	3486
4500	2.2	2968	317	3594
5000	2.15	3080	316	3632
5500	2.15	3194	312	3708
6000	2.15	3299	309	3777
6500	2.1	3379	309	3787
7000	2.1	3468	306	3842
7500	2.1	3551	303	3893
8000	2.1	3628	301	3939
8500	2.1	3701	299	3982

Will Strike Top of Adjacent Stack
Striking Velocity > 1114 fps
Time of Arrival > 444 ms

Conclusions:
No fragments < 2-deg initial angle will strike the top of the stack.

Model 11 Pad Size 400 x 50 NEW = 500,000 lbs
5.6 $W^{1/3}$ = 444.4723 2 Barricades

Initial Velocity (ft/sec)	Initial Angle of Frag Going Over Barrier (deg)	Horizontal Range (ft)	Striking Velocity (ft/sec)	Time (ms)
1200	1.06	885	564	1127
1300	0.93	848	613	1000
1400	0.84	894	623	1016
1500	0.76	904	649	976
1600	0.68	906	679	927
1700	0.62	916	704	894
1800	0.56	919	732	854
1900	0.51	924	759	820
2000	0.47	934	782	794
2500	0.32	972	907	677
3000	0.24	1020	1028	604
3500	0.2	1094	1118	576
4000	0.17	1158	1209	550
4500	0.17	1812	748	1152
5000	0.16	1910	754	1160
5500	0.16	2011	753	1181
6000	0.15	2090	760	1182
6500	0.15	2175	758	1199
7000	0.15	2255	757	1214
7500	0.15	2330	755	1228
8000	0.15	2400	753	1241
8500	0.15	2467	751	1253

Will Strike Top of Adjacent Stack
Striking Velocity > 1114 fps
Time of Arrival > 444 ms

Conclusions:
Some fragments < 2-deg initial angle will strike the top of the stack. Even if a large enough fragment struck the top of the stack, the time of arrival is late enough that the two detonations would not be simultaneous. Therefore, the NEW for Q-D would be one stack (i.e. 500,000 lbs NEW).

Model 12 Pad Size 720 x 125 NEW = 500,000 lbs
5.6 $W^{1/3}$ = 444.4723 2 Barricades

Initial Velocity (ft/sec)	Initial Angle of Frag Going Over Barrier (deg)	Horizontal Range (ft)	Striking Velocity (ft/sec)	Time (ms)
1200	1.77	1306	409	2016
1300	1.58	1321	427	1939
1400	1.4	1333	446	1858
1500	1.26	1195	518	1481
1600	1.13	1196	543	1407
1700	1.03	1203	564	1351
1800	0.93	1203	588	1287
1900	0.85	1208	610	1237
2000	0.78	1213	631	1191
2500	0.52	1230	738	992
3000	0.37	1248	839	851
3500	0.28	1274	937	751
4000	0.23	1322	1020	697
4500	0.19	1356	1115	644
5000	0.16	1385	1214	598
5500	0.14	1423	1299	568
6000	0.13	1485	1341	563
6500	0.12	1535	1390	552
7000	0.11	1574	1449	537
7500	0.1	1602	1520	517
8000	0.1	1681	1500	534
8500	0.1	1756	1481	549

Will Strike Top of Adjacent Stack
Striking Velocity > 1114 fps
Time of Arrival > 444 ms

Conclusions:
Some fragments < 2-deg initial angle will strike the top of the stack. Even if a large enough fragment struck the top of the stack, the time of arrival is late enough that the two detonations would not be simultaneous. Therefore, the NEW for Q-D would be one stack (i.e. 500,000 lbs NEW).

Model 13 Pad Size 720 x 125 NEW = 500,000 lbs
5.6 $W^{1/3}$ = 444.4723 One 8 ft 9 Barricade

Initial Velocity (ft/sec)	Initial Angle of Frag Going Over Barrier (deg)	Horizontal Range (ft)	Striking Velocity (ft/sec)	Time (ms)
3500	0.27	1254	955	731
4000	0.21	1272	1072	650
4500	0.18	1326	1151	617
5000	0.15	1349	1264	569
5500	0.13	1381	1362	537
6000	0.12	1439	1411	529
6500	0.11	1485	1470	517
7000	0.1	1518	1541	499
7500	0.09	1540	1627	478
8000	0.08	1549	1732	452
8500	0.08	1622	1711	466

Will Strike Top of Adjacent Stack
Striking Velocity > 1114 fps
Time of Arrival > 444 ms

Conclusions:
Some fragments < 2-deg initial angle will strike the top of the stack. Even if a large enough fragment struck the top of the stack, the time of arrival is late enough that the two detonations would not be simultaneous. Therefore, the NEW for Q-D would be one stack (i.e. 500,000 lbs NEW).